Biological Assessment and Habitat Characterization of Waimanalo Stream: Establishing Environmental Goals and a TMDL for Watershed Management

STREAM BIOASSESSMENT PROGRAM
Environmental Planning Office
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I. Biological Assessment of Hawaiian Streams

Stream Environments of Hawaii

The Hawaii Stream Assessment (HSA 1990) identified 376 perennial streams in Hawaii. Fifty-seven of these streams are found on the island of Oahu. Hawaiian streams generally share a number of characteristics which set them apart from streams commonly found in continental settings: they are usually short, relatively steep, and flow through deeply incised valleys carved through the volcanic landmass which forms the islands. In streams that have not been impacted by human activities, bed substrate is composed of silt-free, loose cobble and boulder, and persistent coverage of fine sand and sediment is limited to the lower reaches and stream mouth estuaries. Natural flow regimes are dominated by surface runoff, which causes many streams to have flow rates that increase sharply in response to local rainfall. Low flows are often supported by groundwater input, but are variable among streams, and dependent upon the hydrogeological characteristics of inland regions. An extensive network of dams and ditches interrupt and divert streamflow from over half of the State's streams (a majority of streams on Oahu are diverted, Wilcox 1996). These diversions of surface water greatly reduce or eliminate surface flow in many reaches of these streams.

A remarkable assemblage of organisms has evolved to exist in the stream environments of Hawaii (Kinzie 1990). The larger native stream organisms are derived from marine species and retain a marine phase in their life cycles. These animals share a diadromous life history known as "amphidromy" (Table 1). In this life cycle, eggs are laid by adults in freshwater and newly hatched larvae are soon dispersed by the stream flow and transported downstream to the sea, where they are planktonic for a period of several months (Radtke et al. 1988). Post-larval juveniles then move into estuaries and stream mouths and, provided there is sufficient water in the stream channel and no artificial barriers, they begin a strenuous upstream migration. The fish climb using pectoral fins modified to form a ventral sucking disk; the crustaceans simply climb using their legs. Both groups make use of wet areas along stream margins and overhangs, even if at times they leave the water and are briefly exposed to air.

Table 1. Larger native stream fauna of Hawaii.			
Scientific name	Hawaiian name	Biogeographic status	Type of organism
Awaous guamensis	O'opu nakea	indigenous	Freshwater fish (family Gobiidae)
Lentipes concolor	O'opu alamo'o	endemic	Freshwater fish (family Gobiidae)
Stenogobius hawaiiensis	O'opu naniha	endemic	Freshwater fish (family Gobiidae)
Sicyopterus stimpsoni	O'opu nopili	endemic	Freshwater fish (family Gobiidae)
Eleotris sandwicensis	O'opu akupa	endemic	Freshwater fish (family Eleotridae)
Atyoida bisulcata	Opae kala'ole	endemic	Crustacean Freshwater shrimp
Macrobrachium grandimanus	Opae 'oeh'a	endemic	Crustacean Freshwater prawn
Neritina granosa	Hihiwai	endemic	Mollusk Freshwater snail

Within any stream the distribution of native species depends upon channel morphology and the varying degrees of ability of these organisms to ascend and pass steep gradient/high velocity reaches (Nishimoto and Kuamo'o 1991). *Eleotris sandwicensis* , *Stenogobius hawaiiensis*, and *Macrobrachium grandimanus* occur in the lower portions of streams and do not have the ability to climb above high gradient/high velocity reaches. *Awaous guamensis*, *Sicyopterus stimpsoni*, and *Neritina granosa* and adults of these taxa occur from the lower to the middle reaches of streams due to a moderate level of climbing ability, and these taxa show the widest upstream/downstream range. *Lentipes concolor* and *Atyoida bisulcata* have strong waterfall climbing abilities and, as adults, occur highest in streams. These two species have been found above the State's highest waterfalls including Akaka Falls (140m) and Hiilawe Falls (300m) on the island of Hawaii (Englund and Filbert 1997).

The introduction of aquatic organisms is a widespread phenomenon throughout the State, and over 50 species are thought to have become established (Devick 1991). Alien species are considered to contribute substantially to the loss of stream biological integrity, because of interspecific aggression, predation, and competition for resources such as food and space. There is a haphazard pattern of aquatic introductions throughout the State, with fishing/food resource organisms (such as the Chinese catfish *Clarias fuscas*) and pest/vector control organisms (such as the mosquito fish *Gambusia affinis*) distributed more widely than the numerous more recent "accidental" aquarium releases (such as the Poeciliid live bearing guppies and the "feeder shrimp" *Caridina weberi*). With the exception of the amphidromous prawn *Macrobrachium lar,* which was introduced in the late 1950's for fishing/gathering, none of the introduced species have the ability to disperse above barriers and among watersheds (or islands) and are therefore dependent upon human releases for their dispersal.

Assessment of Stream Communities

An index of biotic integrity (IBI) may be used to evaluate community-level characteristics of the biota inhabiting aquatic environments (Barbour et al. 1994, USEPA 1990, Karr and Chu 1997). An IBI is based on scoring a number of individual "metrics", each of which represents an aspect of the aquatic community; metrics can reflect absolute or relative number of species, number of individuals, trophic or reproductive guild, or somatic condition. A metric is some measurable characteristic of a biotic assemblage that reflects ambient conditions. Metrics that are sensitive to human impacts are usually chosen to be included in biological assessments. Ideal metrics include measures of community composition, diversity, and presence or absence of organisms that indicate either least impaired or highly degraded conditions.

Each metric is scored, with the highest score awarded to the least impaired condition. The sum of the scores all of the metrics provide a single semi-quantitative numerical index value which reflects the biological integrity of the stream reach under study (Barbour et al. 1994, USEPA 1997a). "Reference conditions" are defined as the set of highest index scores computed in a region, as determined from a representative sample of least impaired streams. Subsequent comparisons of stream reaches under assessment are then made on a relative basis, for example; an index score that is 90% of the reference condition score might be considered nonimpaired, an index score that is only 10% of reference might be considered severely impaired. The development of metric scores, and the basis for comparison of index values, is done on an ecoregional scale using a data set that includes sites that range in condition from least-impaired to highly degraded.

There are a number of advantages to using comparative biological surveys based on an IBI when evaluating degradation of a stream in response to human activities. Among these are: 1) biological communities reflect an integration of ecological condition (including chemical, physical and biological integrity) and therefore directly assess the status of the waterbody relative to the primary goal of the Clean Water Act (CWA); 2) when criteria for specific impacts do not exist or are difficult to apply (e.g. non-point source impacts that degrade habitat, or in-stream flow standards) biological communities may be the only practical means of evaluation; and 3) monitoring biological communities can be relatively inexpensive, particularly when compared to the cost of assessing toxic pollutants, either chemically or with bioassays (USEPA 1997). Importantly, assessment of biological communities and physical habitat characteristics at multiple sites along a stream course can lead to a watershed-level view of factors that lead to impairment; this larger view can assist managers to geographically identify problem areas and implement controls to reduce causes of degradation.

A pilot program undertaken by the Department of Health Environmental Planning Office (HIDOH 1993, HIDOH 1997) has resulted in the development of an IBI for Hawaiian streams (this specialized index is called the Hawaii Stream Bioassessment

Index or HSBI). Appendix A outlines the specific field protocols used to obtain data used for metric calculations. Metric scores primarily reflect presence/absence or relative abundance of native and introduced fish and the larger invertebrate species (Table 2). Metrics can be awarded a score of 1, 3 or 5 depending on results of a census performed in a 100 meter minimum length of stream. The sum of scores of all six metrics yields the HSBI. The maximum HSBI score is 30, a value that would be achieved in a reference condition stream site with 5 or more native amphidromous species, occurrence of both *Lentipes* and *Sycyopterus*, and no more than one introduced species.

Table 2.
Metric scoring for use in the Hawaiian Stream Bioassessment Index.

METRIC[1]	SCORE 5	3	1
1. Number of native amphidromous macrofauna[2] (S_{NAM})	5 - 8	3 - 4	2 - 0
2. Percent contribution native taxa (PNT)	60% - 100%	40% - 60%	0% - 40%
3. Sensitive native fish species[3] (SNF)	100% - 75%	50% - 75%	0% - 50%
4.Tolerant introduced fish species[4] (TIF)	0% - 20%	20% - 80%	80% - 100%
5. Community weighted average[5] (CWA)	1 - 3	3 - 9.5	9.5 - 10
6. Number of introduced taxa (NIT)	0 - 1	2 - 3	>3

1. Based on visual census using linear or point count methods, or electroshocking.
2. Includes the 5 gobioid fish and larger invertebrates listed in Table 1.
3. Sensitive = native fish that are most affected by habitat and water quality degradation. These are *Sicyopterus* and *Lentipes*.
4. Tolerant = introduced fish that are most tolerant of habitat and water quality degradation and are widespread throughout State. These are the Poecilids , *Xiphophorus* spp and tilapia.
5. The formula used to calculate the CWA is:

$$CWA = \sum \frac{n_i a_i}{N}$$

where n_i represents the number of individuals in the i^{th} taxon and a_i the weighting value for that taxon (Appendix B).

Habitat availability is crucial to existence of life in aquatic environments. An integral part of assessing a biological assemblage is examination of the habitat conditions that support it (USEPA 1997). Therefore a physical habitat characterization is an equally important element of the survey protocol. Appendix A also outlines the specific field protocols used to measure and quantify habitat characteristics used in the evaluation. Each of nine characteristics are measured and awarded an appropriately weighted score. The amount and quality of physical living space is measured at primary, secondary and tertiary levels, each of which has different maximum score. The sum of all scores provides a semi-quantitative index value that, like the HSBI, is compared on a relative basis to a “least-impaired” reference condition. The maximum attainable score for the habitat evaluation is 130, which would represent a stream with loose, silt-free cobble and boulder substrate, frequent alternation of pool/riffle habitat types, a relatively deep channel, a riparian zone with no scars from erosion, and intact vegetation throughout a wide riparian zone.

A set of guideline values is suggested for the purposes of evaluating aquatic life use in Hawaii (Table 3). These values were proposed to differentiate between full support of healthy native communities of organisms and varying degrees of aquatic life use impairment.

Table 3.
Guideline values for interpreting attainment of aquatic life uses in Hawaiian streams.

Habitat (% of reference)	Biological condition (% of reference)
<50% = nonsupport	<30% = impaired
50% - 75% = partial support	30% - 70% = moderately impaired
>75% = supporting	>70% = nonimpaired

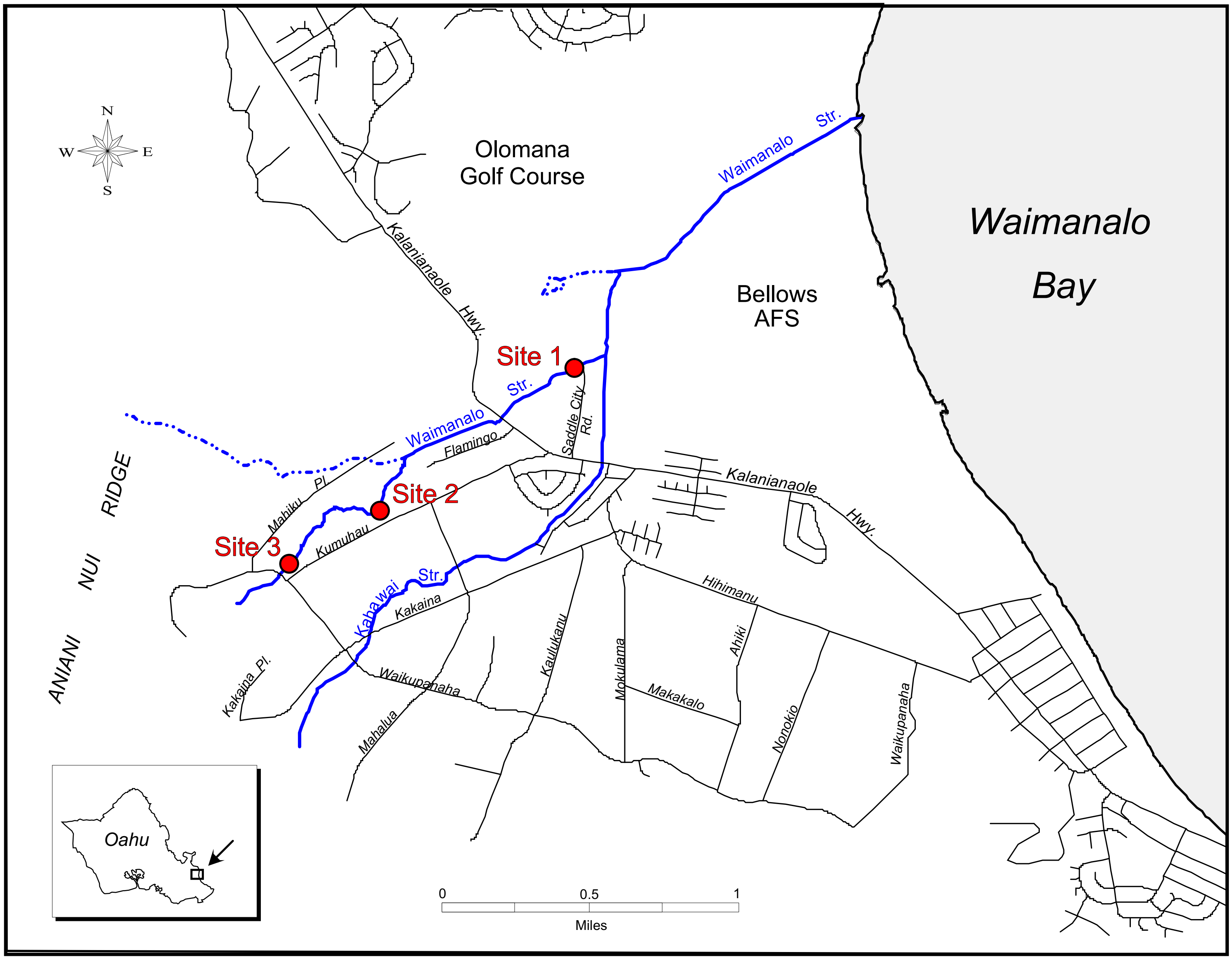
Waimanalo Stream

Three small streams located on Oahu’s windward side; Waimanalo Stream, Kapaa Stream, and Kawa Stream, were identified as highly impaired in a 1996 survey of waterbodies throughout the State (HIDOH 1996). These streams have been given priority status for the development of watershed-based water quality improvement management actions (see draft 1998 Hawaii CWA 305[b] report and proposed 303[d] list of impaired waters). The streams were chosen based on an evaluation of narrative water quality criteria which, among other prohibitions, require that no substances be introduced into State waters that produce undesirable aquatic life, and that no soil particles enter State waters as a result of industrial or agricultural activities. In 1997, Waimanalo Stream was chosen as a study stream to begin a demonstration project to identify causes and results of stream impairment, define achievable environmental management goals to reduce water quality degradation, and begin the process of watershed restoration. Waimanalo Stream was chosen for this demonstration project based upon several factors, including location, size and accessability. A significant factor in choosing Waimanalo Stream was the prospect of community involvement; several local community groups are active in issues of water quality education, and strongly support the prospect of fostering cooperative stakeholder involvement for water quality improvement activities (WWQAG 1997).

Waimanalo Stream is not large, even by current Oahu standards, its median flow is approximately 3-5 cfs. The main stem of Waimanalo Stream is approximately 7.5 km long and originates at the incised valleys of the precipitous "pali" (cliffs) which border the inland area behind the Waimanalo watershed (Figure 1). The headwaters begin in areas of groundwater input at the base of the pali, and the stream flows in a relatively straight channel to its confluence with the sea at Bellows Beach on Waimanalo Bay. Several small tributary channels merge with the main stem in the upper reaches, these channels are dry or nearly so under most weather conditions. The abandoned Kailua Ditch cuts across the back of these valleys but does not entrain water. The Maunawili Ditch is in use (managed and maintained by the State Department of Agriculture) at a higher elevation and flows through a 16 inch pipeline. The effectiveness of the Maunawili Ditch in collecting water from the upper tributaries is minimal, although an accurate estimate of potential water diversion into the ditch system from the stream headwaters was not determined for this report.

The stream in the upper reaches flows through riffles and small pools and over jumbled boulder, cobble and gravel substrate. The wetted channel width is approximately 1-2m. Land uses in this area are limited to pasture, smaller nursery operations, rural house lots, and State lands. State lands include the large parcel

Figure 1. Map of Waimanalo Stream Watershed



inhabited by the “Nation of Hawaii” activist group which has installed gardens, rough dwellings and farm structures in the vicinity of the upper reaches of the stream.

A middle reach of the stream begins at the bridge where Waikupanaha Road crosses the stream; below the bridge the streambed gradient is less steep. Kumuhau Road is aligned parallel to this middle section of stream. No tributary channels enter the stream along this middle section, although there are a number of stormwater drainage ditches that enter the stream channel, these ditches drain rural residential and agricultural areas. Several small perennial springs provide groundwater input to this reach of stream. The stream in this region flows through riffles and large pools over boulder, cobble and gravel with an increasing amount of sedimentation and embedding of the substrate with silt and fine sand. The wetted channel width is approximately 2-3m. Land uses along this reach include pasture lands, rural home sites, moderate density neighborhoods, and numerous nurseries. Nursery operations range from small backyard operations to large, multi-acre commercial enterprises complete with green houses and mechanized farm equipment. Products of these businesses include a range of tropical ornamental plants and flowers, and some specialized food crops (e.g. dryland taro, apple banana). Small amounts of water are pumped out of the stream for irrigation at various points along the upper and middle sections of the stream, but no major dams or diversions are in place.

Below the crossing of Kalanianaole Highway is the lower section of stream, characterized by its even, low gradient. Much of this length of stream has been artificially straightened, especially in the lands in and just upstream of Bellows Air Force Base. Older maps show a considerable amount of wetland area in the vicinity of the lower reaches. None of these wetlands exist today; all have been drained, historically for sugarcane cultivation, but now these lands are in military, pasture and golf course use. A very small (1-2 cfs) named tributary, Kahawai Stream, flows into Waimanalo Stream in this reach. Kahawai Stream runs through the more densely populated areas of the Waimanalo Watershed including the center of the residential and commercial areas. The main stem of Waimanalo Stream in this section flows through broad and very shallow pools and few riffle areas, with cobble and gravel substrate showing a marked amount of sedimentation and embedding due to silt and fine sand. The wetted channel width is approximately 2-4m. Large parcels of shrub-covered government land characterize this reach of the stream, although there are a few homes on large lots near the stream. The stream channel of this reach is managed as a floodway to convey water off of land and to the sea. Stream banks are regularly sprayed with herbicide down to the waters edge to eliminate vegetation. The stream forms a small estuary near its mouth and flows across sand to reach the sea at Bellows Beach.

2. Assessment of Biological Integrity of Waimanalo Stream

Methods

The methods used for this study followed the draft Hawaii Rapid Bioassessment Protocols summarized in Appendix A. Field activities involve choosing a representative reach of stream that is a minimum of 100m in length, surveying nine habitat characteristics, and observing a representative sample of the biological community (fish and larger invertebrates).

In the habitat survey, six channel cross sections are used (located at points 0, 20, 40, 60, 80, and 100m from the bottom of the site) to measure channel width and maximum depth. At three points on each cross section substrate composition and condition are estimated. All pool and riffle sections of the site are mapped and linear measurements of these features are totaled. These values are used to assign scores relating to substrate, pool/riffle ratios and width to depth ratios. Other qualitative scores are assigned relating to channel shape, erosion, and stream bank vegetation.

Sampling stream organisms required the use of an electrofishing apparatus which passes an electric current though the water and stuns and immobilizes fish and crustaceans long enough for their capture. Electrofishing activities were standardized based on time and effort; all sites were sampled by experienced operators for 35-40 minutes. This allowed collection through 60 to 80m of the 100m sites. Animals were held in aerated buckets long enough to complete the sampling run; then they were identified, counted and returned to the stream.

Site Descriptions

Site Waimanalo1

Lower site. Located 200m above the bridge on Saddle City Road. This site was the most altered by human activities. Stream channel appeared straightened. No overstory vegetation, only grasses and shrubs. Vegetation affected by herbicide application on both banks, down to and including plants in the water. Several areas of denuded bank were badly eroded. Shallow pool was the single dominant habitat type present; the long, narrow pool areas were interrupted by two very small (<1m) riffle sections.

Site Waimanalo2

Middle site. Begins 20m below white board bridge near 41-665 Kumuhau Road. Right bank steep and well vegetated with a perennial spring, left bank sloping with some maintained vegetation and some bare soil. Homes, outbuildings and yards close to stream. Mix of boulder, cobble, gravel and silt. Moderate overstory cover with mix of shade and open areas. Mixed habitat types with a large deep pool just upstream of bridge; other areas alternate riffle and small pool.

Site Waimanalo3

Upper site. Located 120m below Waikupanaha Road bridge. Large pool at upper end of site, mixed small pool and riffle throughout rest of site. Mix of boulder, cobble, gravel and silt. Dense overstory cover with deep shade. Smaller areas of eroded soil adjacent to stream. Stormdrain from roadway enters stream channel at this site. The channel at this site is deeply incised and upper banks are uniformly steep.

Results

Scores for each metric and habitat characteristic are shown in Table 4, and score totals are expressed relative to the Statewide reference condition.

Site Waimanalo1

Habitat: score of 17, 13% of reference. This very low score was primarily caused by the cementing of the substrate with fine sand and silt, and the uniform nature of the channel. With the exception of two very small “riffles”, nearly the entire 100m site was a monotonous slow flowing shallow pool. Using the guideline values for evaluation of habitat quality presented in Table 3, the habitat at this site is “non-supporting” for aquatic life use.

Biological metrics: score of 12, 40% of reference. This site had the highest diversity of all sites with 10 species total, four native and 6 introduced. The introduced organisms that flourish under degraded habitat conditions were overwhelmingly abundant at this site: very large numbers of tilapia were present as were the very common Poecilids and *Xiphophorus* sp. The site HSBI score is rather high considering the degraded habitat. This was a result of representation of native fish and crustaceans especially those indicative of lower-stream/estuarine conditions. The sample included large numbers of the native prawn *Macrobrachium grandimanus*. Present in much lower numbers were the eleotrid *Eleotris sandwicensis*, and gobies *Stenogobius hawaiiensis* and *Awaous guamensis*. Using the guideline values for evaluation of aquatic life (Table 3), the score for this site indicates a "moderately impaired" aquatic community.

Site Waimanalo2

Habitat: score of 52, 40% of reference. The frequently alternating riffle and pool habitat supported a much higher habitat score for this site. Bare and eroding soil along one section of bank, and a heavy silt load kept the overall score below the "non-supporting" guideline value.

Biological metrics: score of 10, 33% of reference. Three of eight species native, although this is somewhat misleading because although they are counted as "present", the two atyid shrimp that were found were small juveniles and probably do not represent an established population. Very large numbers of the small, recently introduced indo-pacific shrimp *Caridina weberi* were collected. A single introduced specimen of the introduced crayfish *Procambarus clarki* was found here. It is notable that the hardiest of the native gobies, *Awaous guamensis*, was *not* collected at this site, although three small *Stenogobius* were collected here. The score falls marginally above the guideline value for "moderately impaired".

Site Waimanalo3

Habitat: score of 58, 45% of reference. This site had channel characteristics much like Site 2, although some erosion was evident on the banks of the upper area of the site. The dense upper canopy provided so much shading that lower story shrubs and other plants were sparse, areas of bare soil were common in the riparian zone. This site had the highest habitat score, though still in the range described as “non-supporting”.

Biological metrics: score of 8, 27% of reference. For the introduced species, the community composition of this site was similar to that of site 2. The only native species collected was the single specimen of *Stenogobius hawaiiensis.* The fact that *Stenogobius*, a very poor climber, is present at this mid elevation site indicates that there are no high waterfalls, steep riffles or other high gradient sections of stream from this site to the confluence. This site scored the lowest of all sites in the watershed and is in the guideline range representing an “impaired” aquatic community.

Discussion

The Hawaii Stream Assessment reviewed and summarized existing aquatic resource information regarding perennial streams across the State. Biological information was summarized based on several factors, including the presence of native fish and invertebrates. Waimanalo Stream was given an “M” or moderate ranking for the reported aquatic resources found within the stream. This ranking was based on the presence of *Awaous guamensis*, the most common and widespread of the native climbing gobies.

A number of useful comparisons between Waimanalo Stream and other sites can be made using the scored measures of habitat characteristics and the HSBI. Figure 1 shows scores of the HSBI for a number of other sites plotted with respect to their habitat scores. These scores were all measured using the same field protocols and the

Table 4. Scores of habitat characteristics and metrics for stream study sites in Waimanalo and Waiahole watersheds.

Scored Attribute	Waimanalo1	Waimanalo2	Waimanalo3	Waiahhole2	Waiahole3a	Waiahole3b	Kaluanui1
HABITAT							
Fine substrate	6	8	11	7	16	15	8
Embeddedness	0	7	6	6	16	18	18
Velocity-depth	1	7	6	15	16	16	13
Channel shape	3	8	6	14	11	11	13
Width-depth ratio	0	5	5	12	7	7	5
Pool-riffle ratio	0	4	12	12	12	12	11
Soil/erosion	1	3	3	9	9	9	13
Vegetation	3	6	6	7	9	10	7
Riparian zone	3	4	3	6	9	10	8
BIOL. METRICS							
S_{NAM}	3	3	1	1	1	3	1
%Native taxa	1	1	1	1	1	5	1
Sens. native fish	1	1	1	1	1	1	1
Tol. introd. fish	3	3	3	1	3	5	1
Wtd. average	3	1	1	1	3	3	1

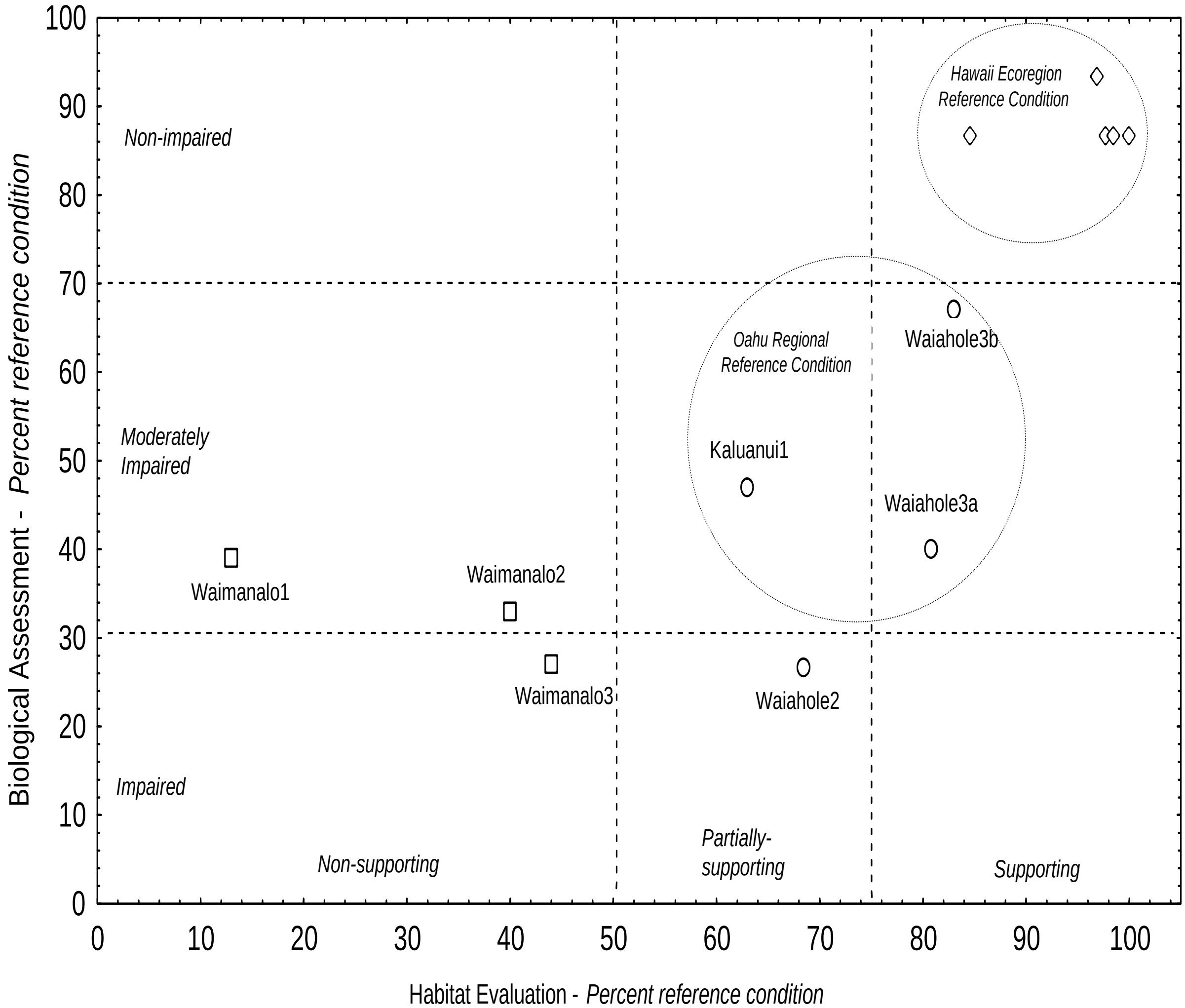
No. introd. taxa	1	1	1	3	3	3	3

Total score (percent reference)							
Habitat	17 (13%)	52 (40%)	58 (45%)	89 (68%)	105 (81%)	108 (83%)	82 (63%)
Biol. metrics	12 (40%)	10 (33%)	8 (27%)	8 (27%)	12 (40%)	20 (67%)	14 (47%)

same measures of community composition and habitat condition. The Hawaii ecoregion reference condition scores represent the highest scores attained in previous surveys which included some of the most remote and least degraded streams in the State (e.g. Hanakapiai Stream on the Na Pali coast of Kauai). No stream on the island of Oahu approximates this “pristine” condition with scores in this range. Streams that exist within a landscape of widespread human alteration, with more than one introduced species, would score substantially below the reference condition. Several stream sites have been surveyed on the windward side of the island of Oahu that could be considered “regional reference conditions” because they represent streams on that island that have suffered less habitat damage and harbor a more intact assemblage of native species. Three sites in the Waiahole watershed and one site on Kaluanui Stream are plotted in Figure 2. Three sites in particular, Waiahole3a, Waiahole3b and Kaluanui1, represent the range of reference condition scores found on Oahu. These scores are considered achievable conditions given the widespread human-caused degradation of watersheds throughout the windward area and the rest of Oahu. Scores will certainly vary within watersheds, with lower scores normally found in the more degraded lower reaches of streams. These lower elevation sites will have more streambank and riparian alteration than sites at higher elevations in the watersheds, and in general will harbor more introduced and fewer native species. Site Waiahole2 is an example of this upstream/downstream variation.

The lower scores at the Waimanalo sites are primarily due to three factors: the effects of fine sediment, observations of bank erosion and riparian vegetation removal, and the presence of large numbers of introduced species. The discrepancies between the “percent fine substrate” scores and the “embeddedness” score on Table 4 show scores in the range of 0-11 in the Waimanalo sites to a range of 8-18 in the Oahu regional reference sites. The differences between scores for “soil/erosion” and “vegetation disruption” are similarly large, with a range of 1-6 in Waimanalo to a range of 7-13 in the Oahu reference sites.

Figure 2.   Statewide and Oahu Regional Reference Condition



The effects of large numbers of introduced species upon the HSBI scores are primarily seen in the metrics scoring “number of native amphidromous macrofauna” and “number of introduced taxa”. Waimanalo Stream, especially the upper sites, had few native species, and overwhelmingly large numbers of individuals of introduced species. The Waiahole sites had far fewer individuals in the samples overall but a relatively greater proportion of native species (and especially the hardy *Awaous guamensis*). The rare (for Oahu) sensitive native species *Sycyopterus stimpsoni* was seen at site Waiahole3b, a site similar in elevation to Waimanalo3.

Some introduced species flourish in degraded stream conditions that reduce the suitability of habitat for native species. In particular, streams that have less frequent riffle/pool alternation, fewer areas of silt-free and loose cobble and boulder, and more areas of warm shallow slow moving water will harbor more profligate herbivorous species such as the Poecilids and tilapia. The other factor that sustains support of such large numbers of introduced species is the food resource. A large input of nutrients that enhance plant growth will encourage high primary productivity, especially the growth of algae in the water column and throughout the benthic region of the stream bed. This in turn supports a large population of herbivorous organisms, particularly tilapia and the poecilids, both of which are omnivorous but consume filamentous algae as their primary food. A reduction in this trend toward eutrophication in the stream may reduce the large biomass of introduced species.

Waimanalo Stream can be considered to have an impaired to moderately-impaired biological community. Habitat attributes are badly degraded, especially those that relate to soil erosion and siltation of the substrate.

III. Setting Environmental Management Goals Using Biological and Habitat Indicators

Water Quality Standards - Designated Uses, Narrative and Numerical Criteria

Water Quality Standards (WQS) are a means to evaluate and manage waters of the State by establishing *designated uses* appropriate for various types of waterbodies and then setting general or specific *criteria* that support those uses. Designated uses are set as a matter of public policy; uses take into account domestic and agricultural water supplies, recreation and navigation, and “aquatic life uses” which encompass the range of conservation goals needed to maintain a waterbody as an ecologically functioning part of the natural landscape. Water quality criteria are then set to protect those uses. Criteria can be narrative or numeric, and sometimes are technical in nature. For example, the narrative criterion expressed in HAR §11-54-04(a)(5) prohibits “substances or conditions or combinations thereof in concentrations which produce undesirable aquatic life”. This statement is one means to describe the need to reduce the possibility of nutrient input leading to eutrophication. Specific criteria for streams put forth a numerical value to accomplish the same goal; for example the specific criteria set a geometric mean of total nitrogen in stream water as not greater than 180μg/ℓ and the geometric mean for total phosphorus as not greater than 30μg/ℓ (HAR §11-54-05.2[b][1] - dry season values). Both the narrative and specific criteria are supportive of the aquatic life use designations for streams found in HAR §11-54-03(b)(1).

Narrative and numerical goals

Waimanalo Stream is considered water quality limited. By definition this means that the stream does not meet water quality criteria on a continual basis, even with the full implementation of point-source controls (in fact there are no point-source discharges in the watershed). The Department of Health and other State agencies do not regularly monitor streams, especially impaired streams, for physical and chemical water chemistry constituents. Therefore this determination was not made based on evaluation of numerical water quality criteria, but on an interpretation of narrative criteria found in the State WQS (HAR §11-54-04). These criteria were evaluated through a series of site visits during which a number of characteristics, such as excessive algal growth, bank vegetation and floating debris were noted (HIDOH 1996).

The subsequent biological assessment, reported here, is meant to evaluate on a semi-quantitative basis the degree to which the stream fails to support the aquatic life uses and other designated uses set forth in the WQS. An additional goal is to identify the causes of impairment, and look for opportunities to begin identifying management options throughout the watershed that will result in support of designated uses.

Exceedance of narrative criteria imply setting narrative goals to focus environmental management activities on reducing deleterious substances from moving into the stream, and to achieve the designated uses set for the waterbody in the WQS. The biological assessment of Waimanalo Stream uses the guidance values of Table 3 to describe the degree to which the biological community and habitat characteristics achieve the designated use set for class 2 inland waters; in particular the "...uses to be protected in this class of water are all uses compatible with the protection and propagation of fish, shellfish and wildlife...". As described above, habitat characteristics do not support these aquatic life uses, and, as determined by the HSBI, one site is biologically "impaired" and the two other sites are marginally determined to be "moderately impaired" with regard to aquatic life uses.

Using the Oahu regional reference conditions and the guideline values as indicators, we suggest the following narrative statement to guide environmental management efforts within the watershed;

> *"Aquatic life uses shall be supported in Waimanalo Stream; the habitat characteristics shall be improved at least into the range of values indicating "partially supporting" habitat, and the biological community shall*

be brought at least into the range corresponding to "moderately impaired" as measured by the HSBI.

Setting numerical goals based on the semi-quantitative values used to determine the HSBI values can be approached using the range of values scored at the regional reference sites as target values. As previously noted, the set of scored habitat observations that relate to siltation and erosion are low in comparison to the reference conditions. Habitat scores could be moved into the "partially supporting" guideline values by instituting sufficient erosion controls to change the following scores: the score for "fine substrate" from a range of 6-8 as seen presently in Waimanalo to a range of 8-16 as seen at the reference sites; the score for "embeddedness" from range of 0-6 to a range of 16-18; the score for "soil loss/erosion" from a range of 1-3 to a range of 9-13; and the score for "vegetation loss" from a range of 3-6 to a range of 7-10 (Table 5). A secondary goal of management activities in the watershed should be to address the loss of biological integrity as indicated by HSBI scores. This goal is secondary because substantially improving stream habitat alone may be enough to foster the in-migration and establishment of more native species in greater numbers, and a concurrent reduction in the degraded habitat that fosters population explosions of profligate and invasive aquatic species. HSBI scores should be targeted to achieve guideline values indicative of "moderate impairment", at a level similar to the Oahu regional reference scores. This result would be seen by a shift of HSBI scores from the range of 8-12 as seen in the Waimanalo watershed to scores of 12-20 as seen at the Oahu reference sites (Table 5).

Derivation of a TMDL for Waimanalo Watershed

A TMDL or total maximum daily load, is a tool for implementing water quality-based pollution control. TMDL development relies upon State WQS and is tied to the relationship between pollution sources and in-stream water quality conditions. The TMDL establishes the allowable loadings or other quantifiable parameters of a waterbody and facilitates development of controls that provide the pollution reduction necessary for a waterbody to meet water quality standards.

Table 5. Management goals for biological and habitat scores		
Attribute	Current score range	Target score range*
Fine substrate	6-8	8-16
Embeddedness	0-6	16-18
Soil loss/erosion	1-3	9-13
Vegetation loss	3-6	7-10
HSBI total score	8-12	12-20

* Numerical expression of TMDL (see below).

The “classic” approach to TMDL formulation is to identify the total assimilative capacity of a waterbody for pollutant mass loadings, which is not to be exceeded by the sum of pollutant loads allocated to individual point and non-point sources. In this approach, the TMDL is expressed in maximum allowable mass load per unit time. TMDLs may be expressed through other appropriate measures instead of mass loads per day (40 CFR 130.2). Alternative approaches can include; expression of numeric targets in terms other than that of loading (such as in terms of watershed wide processes like precipitation or runoff), expression of numeric targets in terms of regional vulnerability to erosion (roads, logging, tilled fields), or in terms of quantifiable measures of channel condition and biological indicators.

The classic TMDL approach based on quantified sediment or nutrient loads is not, at present, a viable option for Waimanalo Stream. The primary reason for this is that there is no data set to begin the process of calculating loads expressed as mass transport over time. A data set that includes stream discharge and the water quality constituent of interest (sediment or nutrients) is required to derive mass load per unit time values. The majority of mass loading is “pulsed” over time, with most transport occurring during unpredictable storm-caused high flow events. An automated sampling regime that ties sample collection times to high flows is required to appropriately collect samples that provide a statistically accurate description of mass transport under these conditions. The Department of Health does not have the resource capacity or technical expertise to institute an adequate sampling regime for a complex natural system such as this.

As described above, other quantifiable parameters that are closely tied to mass loadings may be used in the development of the TMDL. An alternative approach in deriving numerical targets is appropriate for Waimanalo Stream. The scored habitat characteristics and the HSBI multimetric index are sufficiently sensitive to sediment and nutrient loadings to set quantifiable pollution reduction goals based on our current knowledge of the Waimanalo Stream system.

For the numeric component of the TMDL; the pollutant load is defined as the set of conditions supporting the existing scores, the TMDL is defined as the set of conditions supporting the proposed higher scores, and the mechanism to achieve the TMDL is defined as the set of stakeholder actions needed to shift from the lower to the higher scores (discussed below).

There is a considerable and growing body of guidance documentation regarding the formulation of TMDLs (USEPA 1997b). The TMDL model is expressed as:

$$TMDL = LC = WLA + LA + MOS$$

where:

LC= loading capacity, or the amount of loading a waterbody can assimilate *without violating* WQS.

WLA= wasteload allocation, or that portion of the *LC* allocated to point source wasteload (not applicable to Waimanalo).

LA= load allocation, or that portion of the *LC* allocated to *non-point sources*.

MOS= margin of safety, allowance for naturally variability and uncertainty in current knowledge of the system under study.

Using this terminology, the target values of Table 5 are considered equivalent to the load allocation term. The HSBI and scored habitat characteristics represent the cumulative effects of sediment and nutrient-caused degradation (Karr and Chu 1997). The effect of the loads, and not the loads themselves, are measured; therefore, a considerable margin of error is needed in the formulation of the numerical targets. This margin of error is represented by the target values of Table 5 in which ranges, rather than single numbers are listed for habitat and HSBI scores.

TMDL Implementation Possibilities

Subject to preliminary approval of this approach to derivation of TMDL goals; a number of possible management practices may be developed to begin the process of streambank stabilization and to reduce the amount of soil loss into Waimanalo Stream. A review of current land ownership and land use is needed to identify the acreage in pasture, nursery, and “truck crop” agricultural activities. A series of maps and data sets generated using a geographic information system (GIS) showing land ownership and land use is needed to begin this review; as well as an accurate digital GIS “layer” that shows location of both perennial and intermittent streams in the watershed (no map data currently show stream and drainage-way locations accurately).

A simultaneous review of soil management practices and fertilizer/ herbicide/pesticide use for each of the major land uses is also appropriate to identify practices that could be improved to reduce soil loss and nutrient enrichment of the stream. In particular, plowing and tillage activities by truck crop farmers need to be analyzed, as well as the use of fertilizer by small and large nurseries.

Local, State and Federal agencies have a large role to play in direct management of lands in the middle and lower watershed. This is an unusual position for these agencies, which in Hawaii normally manage lands in upper watersheds. In particular, the practice of vegetation removal using herbicides along the lower stream banks should be addressed. (At least one Federally listed endangered waterbird, the alae’ula or Hawaiian gallinule, is found and may nest in the lower watershed. Community groups have previously asked the City and County of Honolulu to seek other means of vegetation control.) If possible, the impact of rural house lots must be determined through quantifying the total acreage devoted to small lots and analysis of possible impacts by the use of cesspools, septic systems and other potential pollutants.

Several community groups have formed to address water quality issues in the Waimanalo watershed, primarily through education. In 1992-1994 a volunteer water quality monitoring program was funded through DOH and UH-Sea Grant for the Kailua Bay-Waimanalo Bay watersheds. Community members were educated about sources of and detection of pollution, and collected data for instructional purposes at several locations in the watershed. Members of this same core group have independently sought and received additional funding from the Hawaii Community Foundation to continue educational programs for school children and use volunteer help to begin a streambank vegetation restoration program in an area of Kahawai stream that is visible from the roadway (and often covered with litter). Also, a environmental grant award to the State Department of Education has resulted in the development of a water quality training program for teachers. Waimanalo area schools have been chosen for this extensive teacher training.

The volunteer monitoring/educational program established by the multimillion dollar KBAC (Kailua Bay Advisory Council) consent decree is presently beginning another volunteer monitoring program in streams and possibly marine/beach sites throughout the region. This major project will have funds available for implementing water quality improvement projects, as they are identified and regionally prioritized.

The community groups have been instrumental in recommending that Federal funds awarded under a USDA Natural Resources Conservation Service grant program be targeted for water quality protection in the Waimanalo watershed. A Farm-A-Syst and Home-A-Syst program will be developed in the region by extension agents from the UH College of Tropical Agriculture and Human Resources Development using these funds. This program will analyze farming and household practices that make use of toxic substances such as pesticides, fertilizers and petrochemicals, and educate farmers and homeowners in methods to reduce effects upon water quality associated with their use.

Through these programs and activities there is potential to reach and work with a large number of stakeholders in the watershed, all of whom have an interest in better management of their land and farms, and to encourage them to participate in stewardship of aquatic environments in the vicinity of their homes and businesses. The Hawaii Department of Health can be a participant in this process in the Waimanalo area by assisting with the planning process, and by developing a management framework that directs restoration activities within the watershed.

Appendix A.

STANDARD OPERATING PROCEDURES

Summary of Field Activities

I. Site location

A. Sites must adequately represent reach under study.

B. Determine length of site: 20-30 times wetted width, 100m minimum.

C. Lay tape along bank, position upper and lower boundaries of site at habitat breaks.

II. Biological survey

A. Determine if visual census (preferred) or electroshock survey[1] will be used (based on number of native organisms likely to be encountered, and potential risk to human health as a result of exposure to stream water).

1. *Linear survey*

a. Enter water at lower end of site, proceed upstream, count and record all fish, larger molluscs and crustaceans.

2. *Point counts*

a. Determine number of points to be examined; minimum of 20 per 100m of stream.

b. Determine location of point using random number table.

I. Choose the size of the quadrat area at the point ($0.25m^2$, $0.5m^2$ or $1.0m^2$) based on physical factors only (water depth, visibility, turbulence, boulders, etc.).

ii. Enter the water, carefully approach point, estimate boundaries, count and record fish and habitat data.

iii. Confirm size of preselected area at point using a marked rod or tape; this task must be done at every point.

iv. Do not use data from sites where fish were unduly startled or visual estimate of quadrat boundaries was wrong.

[1]Note that attached benthic organisms are not included in an electroshocking survey, e.g. *Neritina granosa*.

c. Repeat for next random point in stream.

3. Electroshocking survey

NOTE: personnel involved in electrofishing must have training in shocker operation and safety procedures.

a. Begin shocking at lower end of site, use equal shocking effort for each habitat type encountered.

b. Standardize shocking effort by time (person-minutes), 30-40 minutes for two operators is adequate for most 100m sites of moderate width. Increase time or use additional dip net personnel for larger streams/longer sites.

c. Collect captured specimens in aerated buckets, identify and record numbers after shocking run is completed. Release specimens within the site.

III. Habitat Assessment

A. Primary habitat characteristics

1. *Substrate*: examine the site and visually estimate areal coverage of each substrate type; score based on total prevalence of sand/sediments.

2. *Embeddedness*: examine representative substrate within the site as follows: at cross sections located at points 0, 20, 40, 60, 80, and 100 meters upstream of the bottom of the site observe and record substrate composition and estimated degree of substrate burial at ¼, ½, and ¾ of the way across the stream.

3. *Velocity-Depth*: determine the number of different velocity-depth regimes in the site.

B. Secondary habitat characteristics

1. *Channel shape*: determine the dominant channel shape of the site.

2. *Width to depth*: Measure both thalweg depth and wetted width at points 0, 20, 40, 60, 80, and 100 meters upstream of the bottom of the site. Use the mean W-D ratio of these observations for scoring.

3. *Pool/Riffle Ratio*: measure pool and riffle habitats longitudinally within the site; calculate ratio and assign score.

C. Tertiary Habitat Characteristics

1. *Soil Stability*: observe actual or potential soil displacement throughout the site and assign score.

2. *Vegetation*: evaluate loss of plant biomass along banks due to mowing, clearing , grazing, fire, etc. in areas directly adjacent to stream.

3. *Riparian zone impacts*: evaluation based on width of riparian zone, impacts are landscape-level changes due to human land use patterns such as roads, pavement, lawns.

V. Additional survey data (these data gathering activities require familiarity with and use of a specific meter)

A. Water quality

1. *pH* - use suitable field pH meter.

2. *Conductivity* - use suitable field conductivity meter.

3. *Turbidity* - use suitable nephelometer.

4. *Dissolved oxygen* - use suitable dissolved oxygen meter.

5. *Water and air temperature* - use thermometer.

B. Physical measurements and mapping

1. *Slope of channel* - use clinometer. Measure over the entire length site, or as long a distance within the site as possible.

2. *Altitude, latitude and longitude* - these position measurements can be obtained using a GPS unit and an altimeter.

C. *Stream discharge measurement* (velocity-area method)

1. Locate suitable channel cross section within site (canal-shaped, smooth, no turbulence and moderate velocities is the ideal).

2. Stretch and tie measuring tape about 1 foot above the water (note: it is helpful to adjust tape to obtain a whole number for the proximal value at waters edge).

3. Measure wetted width, divide into about 15 equally-spaced intervals.

4. Measure depth and mean flow at each interval.

5. Calculate incremental flow volumes; sum to give total discharge.

Appendix A (cont.) - Habitat Assessment Data Sheet

Primary Habitat Characteristics -- Possible score of 0 - 20 .

SUBSTRATE

Sand/sediment rare and localized. 0-9% of wetted substrate	Sand/sediment uncommon. 10-19% of wetted substrate.	Sand/sediments widespread. 20-49% of wetted substrate.	Sand/sediments widespread. 50-100% of wetted substrate
SCORE (16-20)	(11-15)	(6-10)	(0-6)

EMBEDDEDNESS

Large interstitial spaces having high volume water flow.	Interstitial spaces limited in size and extent. 25-50% embedded.	Interstitial spaces small and uncommon. 50-75% embedded.	Interstitial spaces rare, >75% embedded.
SCORE (16-20)	(11-15)	(6-10)	(0-6)

VELOCITY-DEPTH

Fast deep, fast shallow, slow deep, slow shallow -- all flows present.	3 of the 4 conditions present.	2 of the 4 conditions present.	One dominant velocity-depth condition.
SCORE (16-20)	(11-15)	(6-10)	(0-6)

Secondary Habitat Characteristics -- Possible score of 0 - 15 .

CHANNEL SHAPE

Deep U-shaped.	Shallow U-shaped.	Broad, flat.	Man-made channel.
SCORE (12-15)	(8-11)	(4-7)	(0-3)

WIDTH TO DEPTH RATIO

Less than 1:8.	Ratio of 1:8 to 1:13.	Ratio of 1:13 to 1:23.	Greater than 1:23.
SCORE (12-15)	(8-11)	(4-7)	(0-3)

POOL TO RIFFLE RATIO

Frequent alternation of habitat types. Ratio of 1:1 to 1:2.	Some alteration of habitat types. Ratios of 1:2 to 1.5.	Habitat types rarely alternate. Ratios of 1:5 to 1:20.	Homogeneous habitat. Ratio <1:20.
SCORE (12-15)	(8-11)	(4-7)	(0-3)

Tertiary Habitat Characteristics -- Possible score of 0 - 10 .

SOIL STABILITY

Stable, no erosion evident.	Little erosion, older eroded areas recovered.	Eroded areas moderate in size and extent.	Unstable, many eroded areas.
SCORE (9-10)	(6-8)	(3-5)	(0-2)

VEGETATION

Vegetation disruption not evident, all "potential plant biomass" intact.	Vegetation disruption has occurred in small localized areas, most "potential plant biomass" remains.	Disruption obvious, widespread, patches of bare soil: little "potential plant biomass" remains	Plant removal severe, mostly bare soil or closely cropped plants; lawns, hedges, crops.
SCORE (9-10)	(6-8)	(3-5)	(0-2)

RIPARIAN ZONE

Riparian zone >4 times stream width, no human impacts.	Riparian zone 2-4 times stream width, minimal human impacts	Riparian zone 1 times stream width, widespread human impacts	Little or no riparian zone (pavement, lawn, cement channel lining, etc)
SCORE (9-10)	(6-8)	(3-5)	(0-2)

TOTAL SCORE:

Appendix A (cont.) - Biological Assessment Data Sheet

STREAM BIOASSESSMENT PROGRAM: Survey Data -- Metrics Calcs

Stream: ______________ Site: ______________ Date: ______________

Survey Method: Point / Linear / Shock Site length/shocking time: ________

Taxa:	Native or Introd:	Number in Sample:	Sens or Tol taxa:	CWA Value:
	N / I		S / T	
	N / I		S / T	
	N / I		S / T	
	N / I		S / T	
	N / I		S / T	
	N / I		S / T	
	N / I		S / T	
	N / I		S / T	
	N / I		S / T	
	N / I		S / T	
Totals:				

Metric	Obs value	Metric Score
1. S_{nam}		
2. PNT		
3. SNF		
4. TIF		
5. CWA		
6. NIT		
	Total:	

Appendix B - Community Weighted Average Calculation

The Community Weighted Average (CWA) is a numerical expression that reflects the relative sensitivity of various taxa to water quality and habitat degradation. The numbers of each taxa in a sample and is calculated as follows:

$$CWA = \sum \frac{n_i\, a_i}{N}$$

Where n_i represents the number of individuals in the i^{th} taxon, a_i the weighting value for that taxon and N the total number of individuals in the sample.

Table B1.
Weighting values of larger Hawaiian stream organisms used in calculating the CWA.

SPECIES	Weighting value
Lentipes concolor	1
Sicyopterus stimpsoni	1
Neritina granosa	2
Atyoida bisulcata	3
Macrobrachium grandimanus	4
Awaous guamensis	5
Stenogobius hawaiiensis	6
Eleotris sandwicensis	7
Introduced species:	
Group 1[1]	10
Group 2[2]	9

1. Introduced species: Group 1 includes taxa that are profligate, predaceous, or cause physical changes in the habitat: for example the Poecilidae, *Microperus* sp., tilapia, and amorheaded catfish.
2. Introduced species: Group 2 includes all other introduced species that exhibit fewer direct effects in the stream environment, for example *Macrobrachium lar.*

This weighted scoring method is based upon the invertebrate “tolerance values” methods of Hilsenhoff (1987) and was developed through the incorporation of physiological and distribution data (Norton et al. 1977) as described in HIDOH 1997.

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